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Interfacial microstructure and mechanical property of Ti6Al4V/A6061 dissimilar joint by direct laser brazing without filler metal and groove

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ABSTRACT

Laser brazing of Ti6Al4V and A6061-T6 alloys with 2 mm thickness was conducted by focusing laser beam on aluminum alloy side, and the effect of laser offset distance on microstructure and mechanical properties of the dissimilar butt joint was investigated. Laser offset has a great influence on the thickness of interfacial intermetallic compound (IMC) layer and the mechanical property of joint. The thickness of interfacial IMC layer is less than 500 nm, and the average tensile strength of the joint reaches 64% of aluminum base material strength, when suitable welding conditions are used. The interfacial IMC is $TiAl_3$. The formation of interfacial IMC layer and its effect on mechanical property of the joint are discussed in the present study.

1. Introduction

Dissimilar joining of titanium and aluminum alloys has potential application in aerospace and automobile industry, which can reduce weight and cost (due to Al alloy) and improve strength, corrosion resistance and high temperature property (due to Ti alloy). However, successful welding of titanium and aluminum alloys is of challenge due to the differences in physical, chemical and metallurgical properties between the two alloys. The key issue is the formation of brittle intermetallic compounds (IMCs) in Ti/Al joints [1].

In recent years, brazing [2], diffusion bonding [3,4], friction stir welding [5] and laser welding [6–12] have been attempted to join Ti/Al dissimilar alloys. Brazing and diffusion bonding are restricted by the size and configuration of the joints. Laser welding is more flexible compared with other welding techniques, and thus attracts more attention from scientists and engineers. It is well known that Ti-Al IMCs form at the joint interface and deteriorate the mechanical properties of laser beam joints of Ti/Al dissimilar alloys [6,7]. Many previous works have been performed to control the thickness of interfacial IMC layer via the use of filler wire containing high silicon content [8–10], which may change IMC type and has a beneficial effect on depressing the growth of IMC layer [13]. It is indicated that $Ti_7Al_5Si_{12}$ and $TiAl_3$ phases are observed at the joint interface, and the thickness of IMC layer can be reduced to about 1 μm provided that proper welding parameters are selected [9]. Some works have been concentrated on the improvement of joint strength by modifying the interfacial reaction nonhomogeneity through the application of rectangular spot laser beam together with suitable welding groove [10], or by adopting the modified joint design such as U-slot joint to increase the length of Al/Ti interface [11,12]. These efforts result in the strength increase of laser beam Ti/Al dissimilar joints, but the tensile strength of the joints is still at the level of about 60–70% of aluminum alloys [12].

Although microstructures in the laser beam Ti/Al dissimilar joint with the use of high silicon filler wire and the influence of interfacial IMC layer morphology on the fracture behavior of the joint have been demonstrated [9,14], the fundamental aspect about the formation mechanism of IMCs at the joint interface of Ti/Al alloys is still not understood comprehensively, and the effect of interfacial IMC layer thickness on the mechanical properties of the joint is unclear. In the present study, the Ti6Al4V and A6061 alloys, which are widely used in the industry, are butt-welded via fiber laser brazing without addition of filler wire, and influence of laser offset distance on the interfacial microstructures and mechanical properties of the dissimilar joints is investigated. The formation of interfacial IMC layer and its effect on the mechanical properties of the joint are discussed.

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2. Experimental details

Ti6Al4V and A6061 plates with dimensions of 150 mm × 75 mm × 2 mm were used in the present study. The chemical composition and mechanical properties of the two alloys are shown in Tables 1 and 2, respectively.

The Ti6Al4V and A6061 plates were joined by an IPG YLR-10000 fiber laser welding system, and the welding parameters are given in Table 3. The laser power was 4 kW, and the welding speed was 4 m/min. Laser offset from 0.3 to 1.2 mm towards aluminum alloy was selected in this investigation. The laser power and welding speed used in the present work were determined according to pretest results, which show that 4 kW and 4 m/min are the optimum parameters for the laser welding of A6061 alloy plate with thickness of 2 mm. Before welding, the joint surface of the titanium and aluminum alloys was machined by a milling machine. During welding, the focus position was kept on the top surface of aluminum alloys, as shown in Fig. 1, and both top and bottom surfaces of the joints were shielded using ultra-pure argon gas (99.999%).

The joints were cross-sectioned perpendicularly to the welding direction for metallographic analysis. The microstructures of joints were examined with optical microscope (OM), scanning electron microscope (SEM, JEOL: JSM-6500F) equipped with an energy-dispersive X-ray spectrometer (EDS) and transmission electron microscope (TEM, JEOL: JEM-4000EX), operating at 400 kV. The specimens for OM and SEM observation were ground and polished. The specimens for OM were etched with Keller's etchant (1.0 ml HF + 1.5 ml HCl + 2.5 ml HNO_3 + 95 ml H_2O) before observation. Backscattered electron images of SEM were used to analyze the interfacial IMC layer. The IMC layer was observed in detail with TEM. Thin foils for TEM observation were prepared using a focused ion beam instrument. The sampling location for TEM was about 0.5 mm from the top side, as shown in Fig. 1.

Tensile specimens were cross-sectioned perpendicular to the welding direction (Fig. 1), and both top and bottom surfaces of tensile specimens were machined to be flat in order to avoid the influence of excess weld metal or lack of weld metal on joint strength. After machining, the thickness of the tensile specimen became about 1.5 mm. The strength of joint was evaluated via tensile test at room temperature using a testing machine INSTRON 5500 at a cross head speed of 0.05 mm/min. Three specimens were tested for each welding condition, and the average value was used to evaluate the tensile strength of joint. Joint fracture surface was observed by OM and SEM. Composition at different regions of the fracture surface was analyzed by EDS. Hardness measurement was performed on the metallographic specimens crossing the joints at mid thickness using a Vickers indenter and a load of 490 mN, and the distance between two neighboring indentations was 100 μm.

3. Results

3.1. Macrostructure and microstructure of joint

Appearances of Ti6Al4V/A6061 laser welded joints with various laser offsets are shown in Fig. 2. Macrostructure and microstructure of cross-sections of the joints are given in Figs. 3 and 4, respectively. It can be seen that the laser offset has a great influence on the formation of joints. When laser offset is 0.3 mm, both top and bottom surfaces of the joint are not smooth and there is much spatter on the surfaces (Fig. 2a and b). Both titanium and aluminum alloys are melted at the joint interface, and a lot of pores are developed at aluminum alloy side in the weld zone (Fig. 3a). Besides, some microcracks are formed at titanium alloy side (Fig. 4a). When the offset is 0.6–0.7 mm, the joint formation gets better (Fig. 2c–f), but titanium alloy is partly melted (Fig. 3b and c) and some pores are formed in the weld zone (Fig. 4b and c). Detailed microstructural examination shows that various IMCs such as $TiAl_3$, $TiAl_2$, TiAl and Ti_3Al are present in the mixed regions of melted titanium and aluminum alloys, depending on the mixing extent. When laser offset is increased to 0.8–1.0 mm, weld surface becomes clean and smooth (Fig. 2g–l). From the macrographs of cross-sections of the joints

Table 2
Mechanical properties of base materials.

Alloys	Tensile strength σ_b(MPa)	Yield strength $\sigma_{0.2}$ (MPa)	Elongation (%)
A6061P-T6	318	289	11.2
Ti6Al4V	952	877	12.6

Table 3
Parameters for dissimilar butt-welding of Ti6Al4V and A6061.

Laser power, kW	4
Welding speed, m/min	4
Beam diameter, mm	0.48
Arc shielding gas, L/min	30
Back shielding gas, L/min	50
After shielding gas, L/min	130
Laser offset towards Al alloy, mm	0.3–1.2

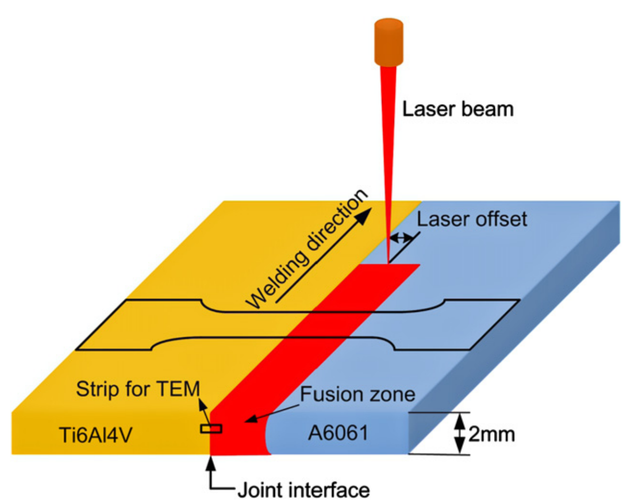

Fig. 1. Schematic drawing of laser welding of Ti6Al4V and A6061 without filler wire and the sampling location.

Table 1
Chemical composition of base materials (wt%).

Alloys	Ti	Al	Si	Fe	Cu	Mn	Mg	Cr	Zn	V	C	O	N	H
A6061P-T6	0.02	Bal.	0.63	0.29	0.27	0.07	1.00	0.17	0.01	–	–	–	–	–
Ti6Al4V	Bal.	6.21	–	0.135	–	–	–	–	–	3.93	0.023	0.126	0.003	0.002

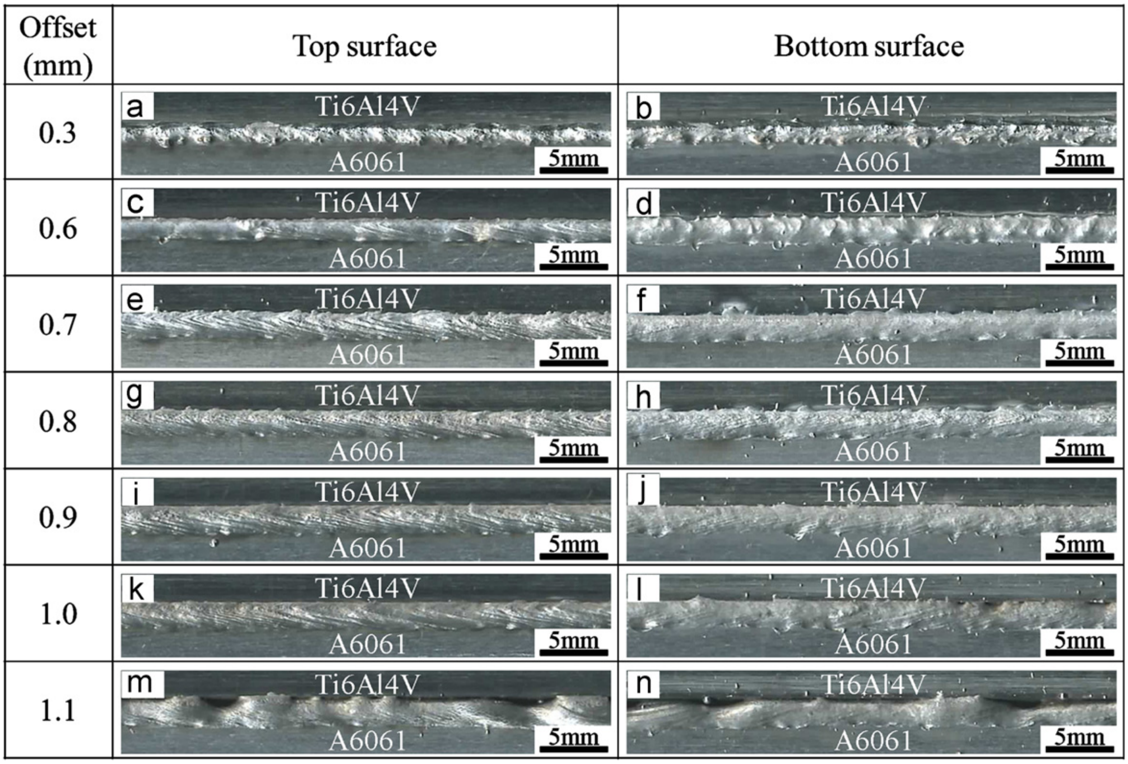

Fig. 2. Appearance of Ti6Al4V/A6061 laser welded joints with various laser offsets.

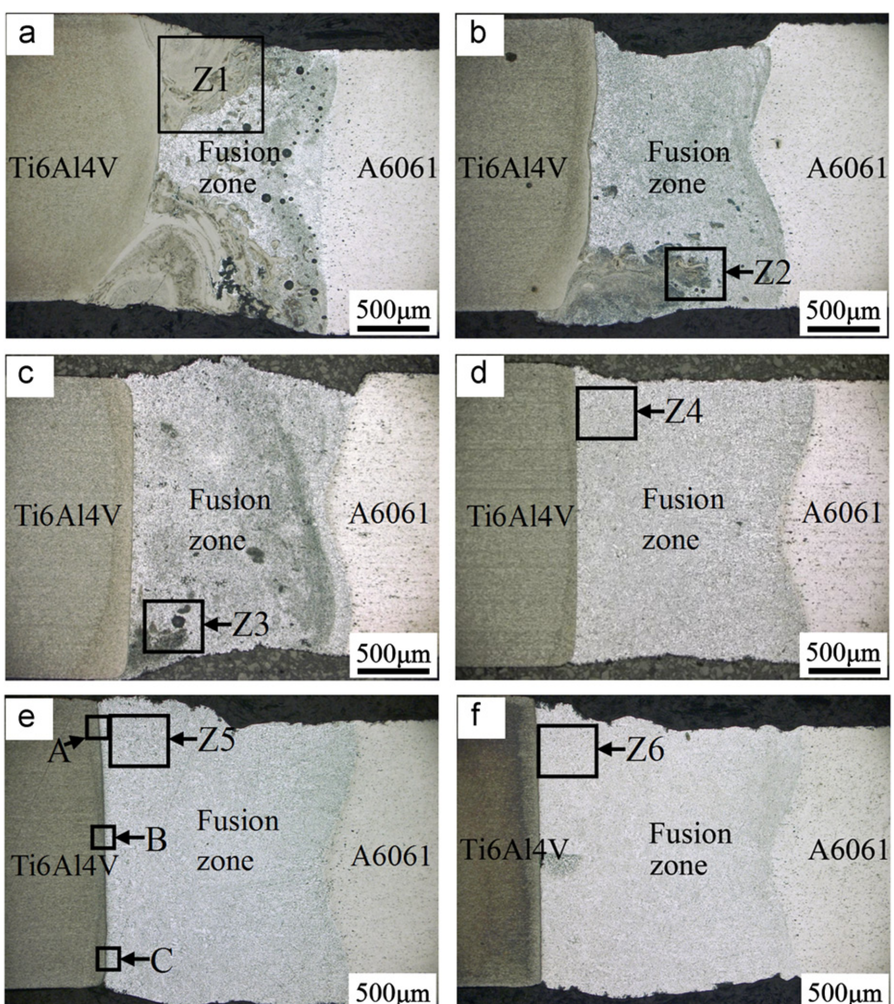

Fig. 3. Cross-section of Ti6Al4V/A6061 joints with various laser offsets: (a) 0.3 mm, (b) 0.6 mm, (c) 0.7 mm, (d) 0.8 mm, (e) 0.9 mm and (f) 1.0 mm.

(Fig. 3d–f), it is clear that titanium is not melted, while the melted aluminum wets titanium surface at the interface, so that brazing joints are produced. When the offset is more than 1.1 mm, Ti6Al4V and A6061 plates are not soundly joined together (Fig. 2m and n).

It can also be seen from Fig. 4d–f that the DAS (dendrite arm spacing) in the fusion zone of Al alloy adjacent to the interface with 0.8, 0.9 and 1.0 mm laser offset is at the same level. In addition, there is not much difference in the grain size in fusion zone with different laser offsets.

Fig. 5 shows the microstructure of the joint with 0.8 mm laser offset. The Ti alloy is not melted at the interface, but is affected by the thermal cycle of laser welding process. There is a heat-affected zone (HAZ) adjacent to the interface at Ti alloy side. In this zone, volume fraction of α phase (gray color) seems to increase, while the proportion of β phase (white color) decreases as compared with Ti alloy base metal, but β phase is still surrounding α phase (as in the base metal). Besides, acicular phase appears in HAZ of Ti alloy, and this acicular phase is

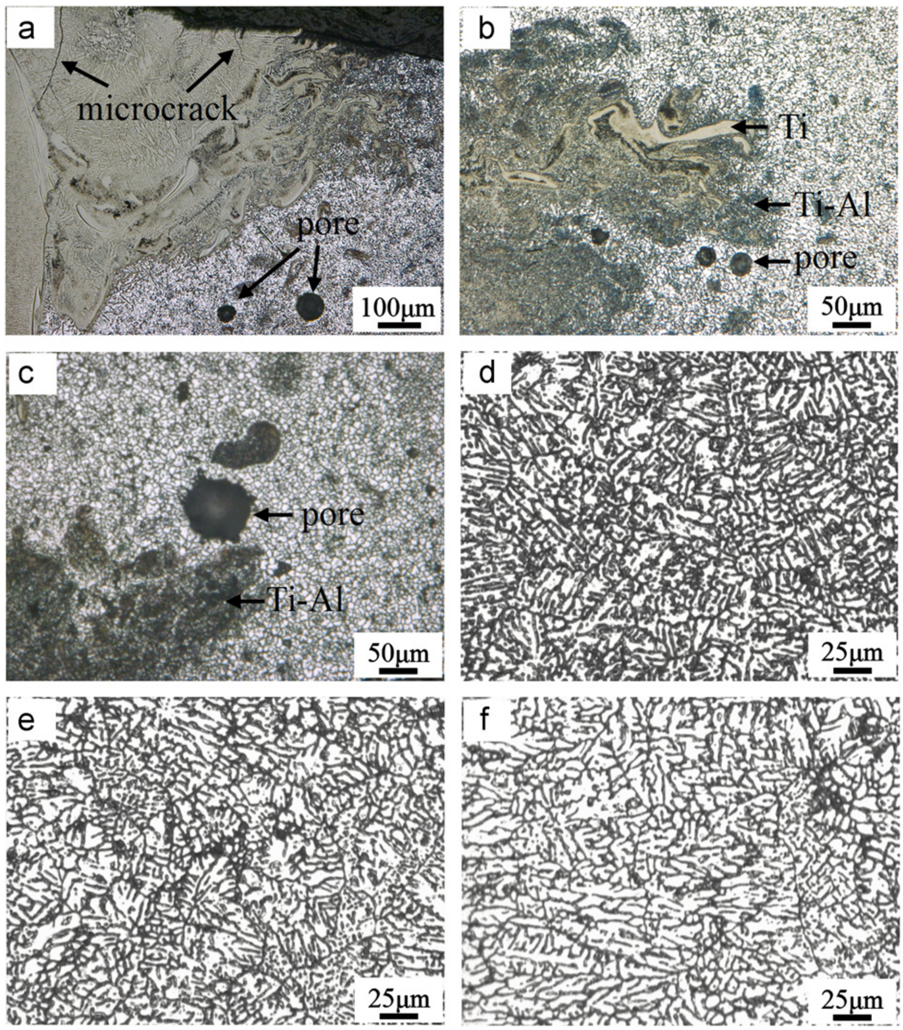

Fig. 4. Microstructure of the joints: (a) zone Z1 in Fig. 3a, (b) zone Z2 in Fig. 3b, (c) zone Z3 in Fig. 3c, (d) zone Z4 in Fig. 3d, (e) zone Z5 in Fig. 3e, (f) zone Z6 in Fig. 3f.

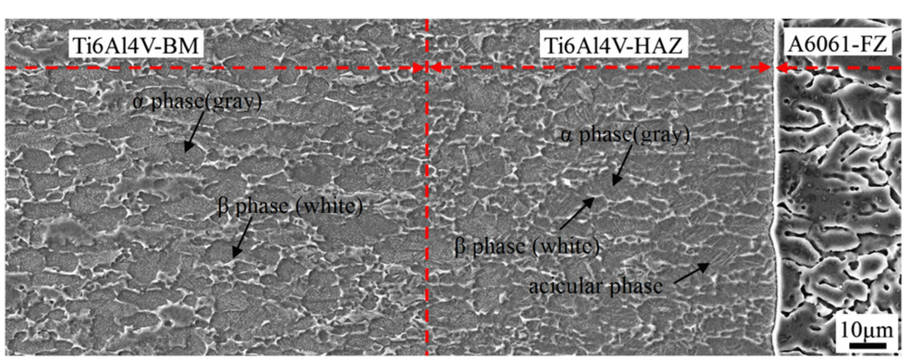

Fig. 5. Microstructure of the joint with 0.8 mm laser offset.

suggested to be α' martensite phase, which results from the fast cooling during phase transformation. This microstructural feature is similar to that of HAZ in laser welding Ti6Al4V alloy [15].

3.2. Interfacial microstructure

Fig. 6 gives interfacial microstructure of Ti6Al4V/A6061 laser brazing joint with 0.9 mm laser offset. The SEM backscattered electron images of three zones, i.e. zone A, B and C shown in Fig. 3e, are presented for the joint. The interfacial IMC layer is a discontinuous serrate-shape. Obviously, the thickness of the IMC layer tends to decrease from top zone (zone A), through middle zone (zone B) to bottom zone (zone C) of the joint. The IMC layer thickness is about 0.8 μm in the top zone and 0.2 μm in the bottom zone. The average thickness of IMC layer in zone A, B and C is 0.48 μm.

Fig. 7 shows interfacial microstructures at the top of joint with various laser offsets. When the laser offset is 0.7 mm, the interfacial IMC layer has thick continuous morphology and discontinuous club-shaped morphology. The club-shaped layer seems to be

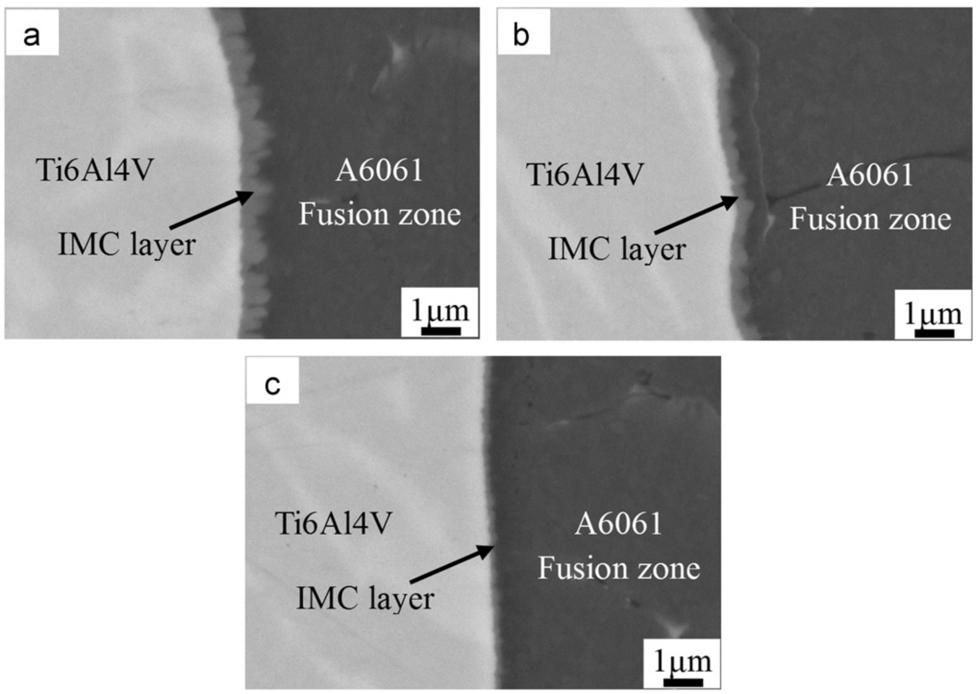

Fig. 6. Interfacial microstructures of Ti6Al4V/A6061 joints with 0.9 mm laser offset: (a) zone A, (b) zone B and (c) zone C. Zone A, B and C are indicated in Fig. 3e.

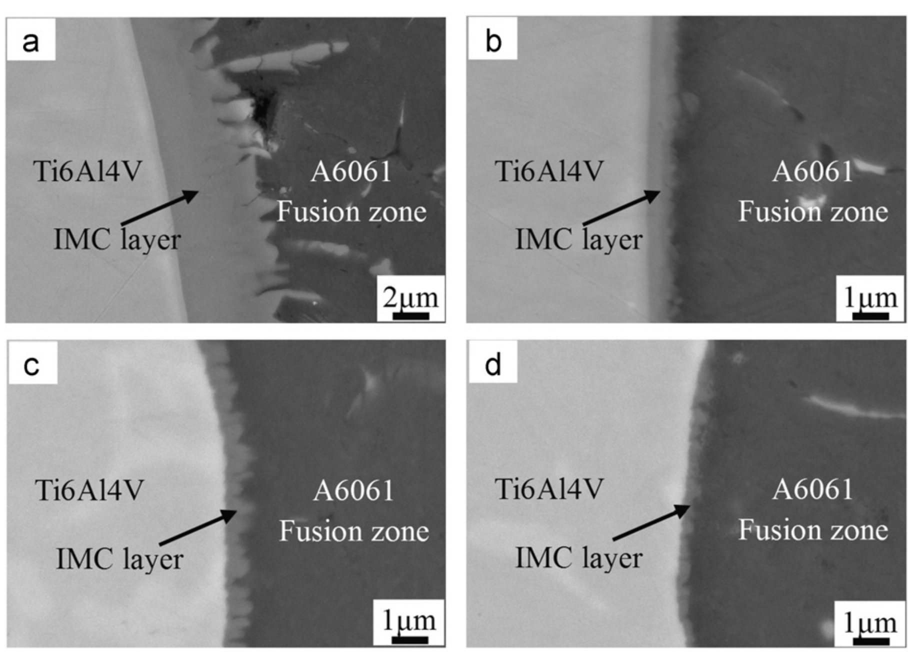

Fig. 7. Interfacial microstructures at top zone of Ti6Al4V/A6061 joints with various laser offsets: (a) 0.7 mm, (b) 0.8 mm, (c) 0.9 mm and (d) 1.0 mm.

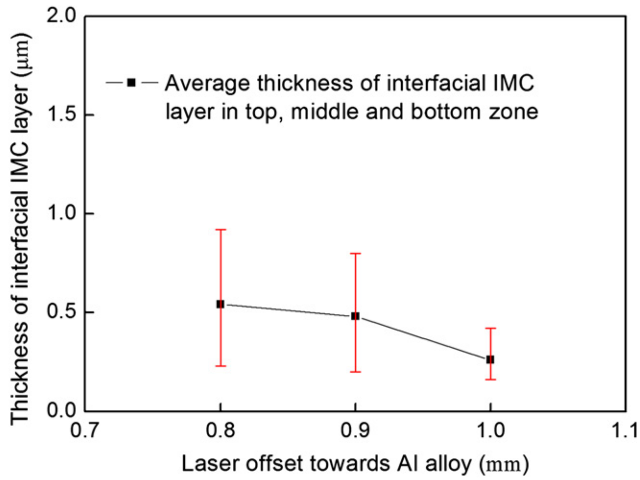

Fig. 8. Thickness of interfacial IMC layer with various laser offsets.

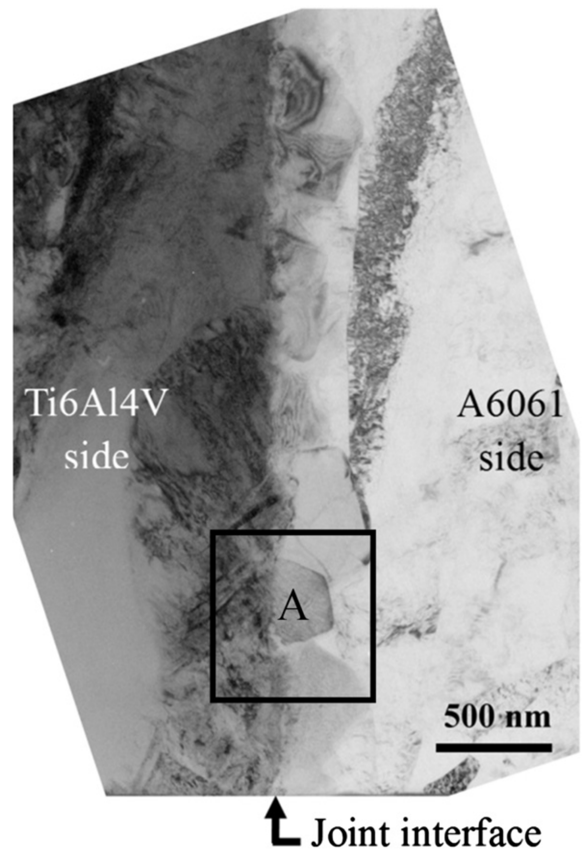

Fig. 9. TEM image of interfacial IMC layer (laser offset = 0.9 mm).

broken in fusion zone of Al alloy. The interfacial IMC layer is identified as $TiAl_3$ by EDS. When the laser offset is increased to 0.8 mm, the IMC layer exhibits a continuous morphology. When the laser offset is further increased to 0.9–1.0 mm, the IMC layer shows a discontinuous serrate-shape. Neither pores nor cracks have been obviously observed at the region adjacent to interfacial IMC layer in the joints with laser offset of 0.8–1.0 mm by means of OM and SEM, as shown in Figs. 3 and 7.

Fig. 8 presents the average thickness of interfacial IMC layer as a function of laser offset in the range of 0.8–1.0 mm. The thickness of interfacial IMC layer of the joints with laser offset of 0.7 mm and less is not included in Fig. 8 because titanium alloy is partly melted and large-size pores (with tens of microns) are formed in the weld zone in these joints. It can be seen from Fig. 8 that the interfacial IMC layer thickness decreases with increasing laser offset. When laser offset is increased to 1.0 mm, the IMC layer thickness becomes extremely thin, and the average thickness of IMC layer is about 0.26 μm. It should be noted that when laser offset is 1.1 mm or larger, Ti6Al4V and A6061 plates cannot be soundly joined together.

Fig. 9 shows TEM image of interfacial IMC layer with laser offset of 0.9 mm, as an example. The selected area electron diffraction patterns at different phases are given in Fig. 10. It is obvious from Fig. 9 that the interfacial IMC layer consists of 1–2 grains of intermetallic phase, which forms at aluminum side of joint interface, and the thickness of the IMC layer is less than 0.5 μm. Pores or voids were not found at the Ti6Al4V/A6061 laser brazing joint in the present work; however, it should be noted that only an extremely-small part of the joint (with length of tens of microns) was examined by TEM. The interfacial IMC is identified as $TiAl_3$ by the electron diffraction pattern (Fig. 10c). The electron diffraction of the interfacial IMC layer at other regions demonstrates that almost all the interfacial IMC at Ti6Al4V/A6061 laser brazing joints with 0.8–1.0 mm laser offset is $TiAl_3$.

3.3. Hardness

The hardness profiles of cross-section of the joints with 0.3 and 0.9 mm laser offset are presented in Fig. 11. When the laser offset is 0.3 mm, the hardness at the joint interface of the Ti alloy side is higher than that of the Ti alloy base metal, because lots of IMCs are formed at the interface and the IMC layer is thick. Some melted Ti alloy is involved in the fusion zone of the Al alloy, and $TiAl_3$ is formed, thus the hardness is locally increased at this region (as shown in Fig. 11a). When the laser offset is 0.9 mm, the hardness at the joint interface seems to be lower than that of the Ti alloy base metal. This is because the interfacial IMC layer is so thin that the hardness test indention covers not only the joint interface zone but also the fusion zone of Al alloy, the latter having much lower hardness than Ti alloy base metal. Fig. 11b also shows that the hardness of the fusion zone of Al alloy is lower than Al alloy base metal.

3.4. Tensile strength and fracture analysis

Tensile strength of the joints is shown in Fig. 12. It is found that the laser offset has a great influence on the tensile strength of joint. The tensile strength increases when the laser offset is increased to 1.0 mm. The highest average tensile strength of Ti6Al4V/A6061 joint is 203 MPa, which is 64% of aluminum alloy base metal. The highest individual tensile strength of Ti6Al4V/A6061 joint is 230 MPa, which is 72% of aluminum alloy base metal. From top surface of the tensile specimens after tensile test (which is also exhibited in Fig. 12), it can be seen that the joint fractures along the interface of the joint when laser offset is 0.6 mm. The joint fractures partly in the fusion zone of Al alloy and partly along the interface of the joint when the laser offset is increased to 0.7–0.8 mm. The joint mostly fractures in the fusion zone of Al alloy, although some small area fractures at the interface when the laser offset is further increased to 0.9–1.0 mm.

Fig. 13 reveals fracture surface from both Al alloy and Ti alloy side of the joint with 1.0 mm laser offset. Fig. 13a and b are the optical image of whole fracture surface. The gray area takes up almost whole fracture surface, except a small area with yellow color in the zone Z2 and Z4. The SEM images of zone Z3 and Z4 are

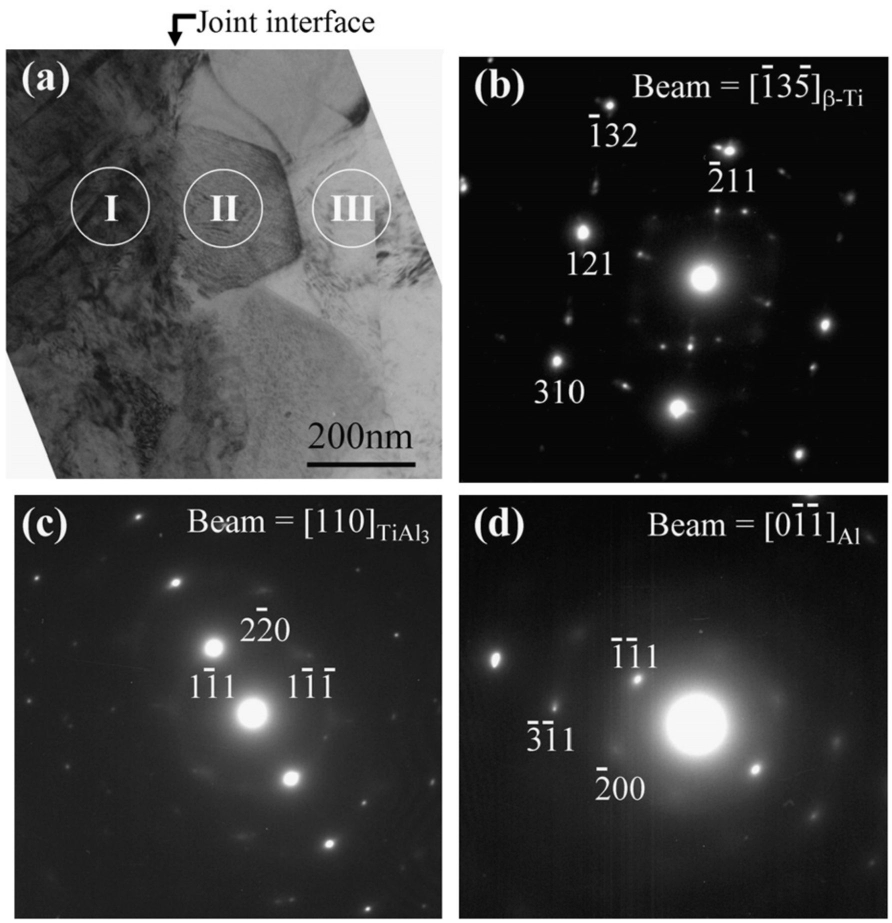

Fig. 10. Selected area electron diffraction patterns at different phases: (a) TEM image, indicated by A rectangle in Fig. 9, (b) zone I, (c) zone II and (d) zone III.

given in Fig. 13c and d, respectively. Most of fracture surface is ductile fracture surface (Fig. 13c), while small area located in zone Z4 with yellow color shows brittle fracture surface (Fig. 13d). The amplified SEM images of zone Z1, Z2, T1 and T2 at Al alloy side and Ti alloy side are presented in Fig. 14. The fracture surface at ductile fracture region (the gray area in Fig. 13a and b) consists of dimples, and EDS analysis shows that the composition at the surface of these regions is similar to A6061 base metal (Fig. 14a and c). This result suggests that the joint mainly fractures in fusion zone of Al alloy. The yellow area Z2 and Z4 in Fig. 13a and b exhibit brittle fracture with sub-microcracks, and the compositions at these zones are close to $TiAl_3$ (Fig. 14b and d). This implies that $TiAl_3$ phase is brittle and may induce brittle fracture of the joint.

Fig. 15 shows the tensile strength of joints as a function of area fraction of dimple pattern of Al on fracture surface (i.e. the area ratio of ductile fracture surface to whole fracture surface). The area fraction is measured from optical and SEM images of fracture surface of tensile specimens. With the increase of the percentage of dimple pattern, the tensile strength of joints is enhanced.

4. Discussion

As described above, direct welding of Ti6Al4V/A6061 dissimilar alloys by fiber laser beam without filler metal can produce sound joints with good appearance, if proper welding parameters are selected (Figs. 2 and 3). In the present work, the proper welding parameters are 4 kW laser power, 4 m/min welding speed and 0.8–1.0 mm laser offset at aluminum alloy side. When the laser offset is 0.7 mm or less, titanium alloy is partly melted, and welding defects such as crack and porosity are present in the joint. The reason of the cracks formed in the fusion zone is that the IMCs ($TiAl_3$, $TiAl_2$, TiAl and Ti_3Al), which are formed in large amount in the fusion zone, have almost no ductility to withstand the thermal stresses [6]. When the laser offset is 1.1 mm or larger, on the other hand, the melted aluminum alloy could not touch and spread out on the titanium alloy very well, so that Ti6Al4V and A6061 alloys cannot be joined soundly.

The laser joining mechanism of Ti6Al4V/A6061 dissimilar alloys is the formation of intermetallic phase $TiAl_3$ at the interface, which metallurgically connects Ti6Al4V and A6061 plates together (Figs. 9 and 10). The $TiAl_3$ phase forms and grows at A6061 side (Fig. 9), suggesting the formation and growth of $TiAl_3$ phase is controlled by the diffusion of Ti atoms through the interface of $TiAl_3$ phase and titanium alloy and $TiAl_3$ phase itself. The thickness (d) of $TiAl_3$ layer is dependent on the temperature (T) and residence time (t), and can be expressed by the following equations [16].

$$d^2 = Kt \quad (1)$$

$$K = K_0 \exp(-Q/RT) \quad (2)$$

where K_0 is the proportion constant, Q is the activation energy, R is the gas constant and T is the absolute temperature. With increasing laser offset while keeping the laser power and welding speed constant, the maximum temperature at the interface of Ti/Al joint becomes lower, and the residence time at the temperatures where

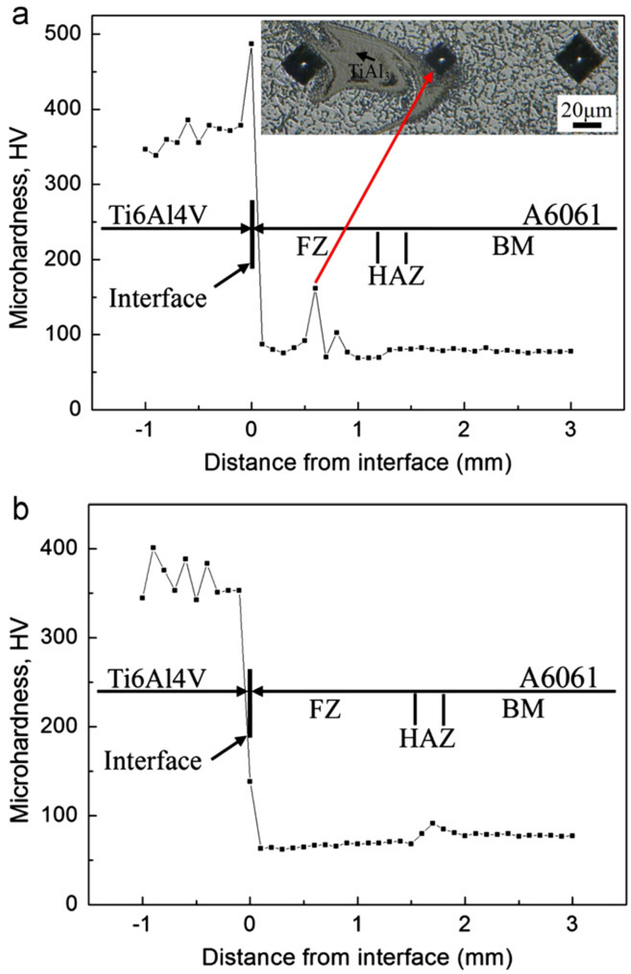

Fig. 11. Hardness profile of cross-section taken perpendicular to welding direction with different laser offsets: (a) 0.3 mm and (b) 0.9 mm.

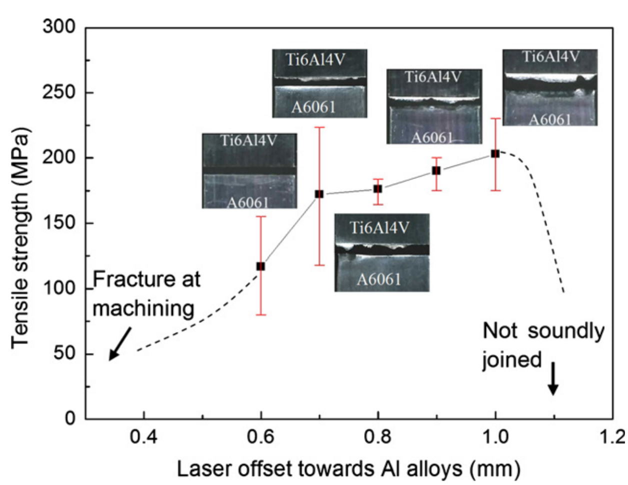

Fig. 12. Tensile strength and fracture analysis with various laser offsets.

the diffusion of Ti atoms is possible becomes shorter. As the result, the thickness of interfacial IMC layer becomes thinner (Fig. 8).

It has well been established that the thickness of interfacial IMC layer has a great influence on the joint strength of dissimilar metals [17–19]. In the present work, it can be found from Figs. 8 and 12 that the tensile strength of joint becomes higher monotonously as the thickness of $TiAl_3$ layer becomes thinner. This result seems to be a little different from those reported by W.H. Sohn [4] and S. Kuroda [20]. Sohn described that the joint strength increased slightly with the thickness of the interfacial IMC layer when TLP (Transient Liquid Phase) bonds Ti/Al dissimilar alloys with Al–Si filler metal [4], and Kuroda reported that the tensile strength of A6061/SUS316 solid state diffusion bonding joint increased and then decreased with increasing thickness of reaction layer [20]. In these previous works, the fact is that when the reaction layer is at smaller thickness, tensile strength decreases due to insufficient contact at joint interface, while at larger thickness, tensile strength decreases due to formation of cavities at the interface. In fact, the result of the present study is in accordance with those of previous works. In the present study, when the laser offset is too small (e.g. 0.7 mm or less), thick IMC layer is formed with accompanying porosity and microcracks, and the joints fracture at IMC layer. When the laser offset is too large, on the other hand, the plates are not soundly joined together, and the joint strength is definitely low. However, when the laser offset is at a proper range (e.g. 0.8–1.0 mm), interfacial IMC layer is integral without formation of obvious pores or cracks, and joint strength decreases with the increase in IMC layer thickness. Besides, the fracture location tends to be changed from fusion zone of Al alloy to the interface between IMC layer and fusion zone of Al alloy with increasing IMC layer thickness (Figs. 13–15). Similar results are also reported by other researchers [17–19]. In Tanaka's work [18], for example, the joint strength of dissimilar friction stir welds of mild steel and various aluminum alloys (1100 and 5052 alloys) increased exponentially with a reduction in the IMC layer thickness. Steel/1100 and Steel/5052 joints with thin IMC layers failed in the aluminum base metal, while the joints with thick IMC layers failed at the joint interface [18]. In the present study, the mechanism for the joint strength reduction with the increase of IMC layer thickness is supposed to be that the vacancies and/or nano-sized micro-voids, which cannot be observed by OM and SEM and are hardly found with TEM since the TEM-examined length of joint interface is too short, may form at the Al alloy side adjacent to the interface between the IMC layer and Al alloy, as a result of interfacial reaction of Ti and Al [19]. With the progress of reaction between Ti and Al (i.e. with the increase in the thickness of IMC layer), vacancies and/or nano-sized micro-voids probably become more and more, and sub-microcracks likely form in IMC layer (Fig. 14b), which may reduce the joint strength.

It is also interesting to note that when the percentage of dimple pattern of fracture surface is higher than 90%, the highest joint strength is just about 72% of the Al alloy base metal, as can be seen from Fig. 15. This can be explained by the decreased hardness (or strength) of the fusion zone of Al alloy. As shown in Fig. 11b, the hardness of the fusion zone of Al alloy is lower than Al alloy base metal. In order to find out the strength of fusion zone of Al alloy, two A6061 alloy plates with thickness of 2 mm were laser welded under the same laser power and welding speed (i.e. 4 kW laser power and 4 m/min welding speed). The ultimate tensile strength of this joint is 232 MPa, which is 73% of Al alloy base metal strength. This is because A6061 alloy base metal was strengthened by precipitation hardening heat treatment at T6 condition, but the fusion zone was at the as-welded condition.

Comparing the present work with other works [8–10,14] dealing with the laser dissimilar-joining of titanium alloy and aluminum alloy, it can be found that the interfacial IMC layer is not only thinner but also more homogeneous than that reported in the previous works, in which the IMC layer is still somewhat uneven along the interface despite that interfacial reaction nonhomogeneity can be improved by rectangular spot with relatively uniform energy distribution combined with filler wire and V-shape groove on parent

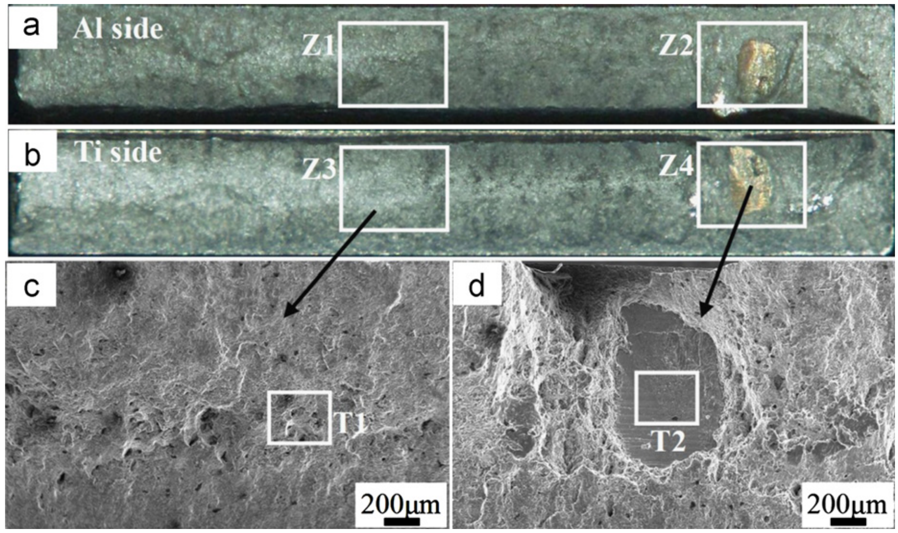

Fig. 13. Fracture surface of the joint with 1.0 mm laser offset: (a) optical image of fracture surface at Al alloy side, (b) optical image of fracture surface at Ti alloy side, (c) SEM image of zone Z3 and (d) SEM image of zone Z4.

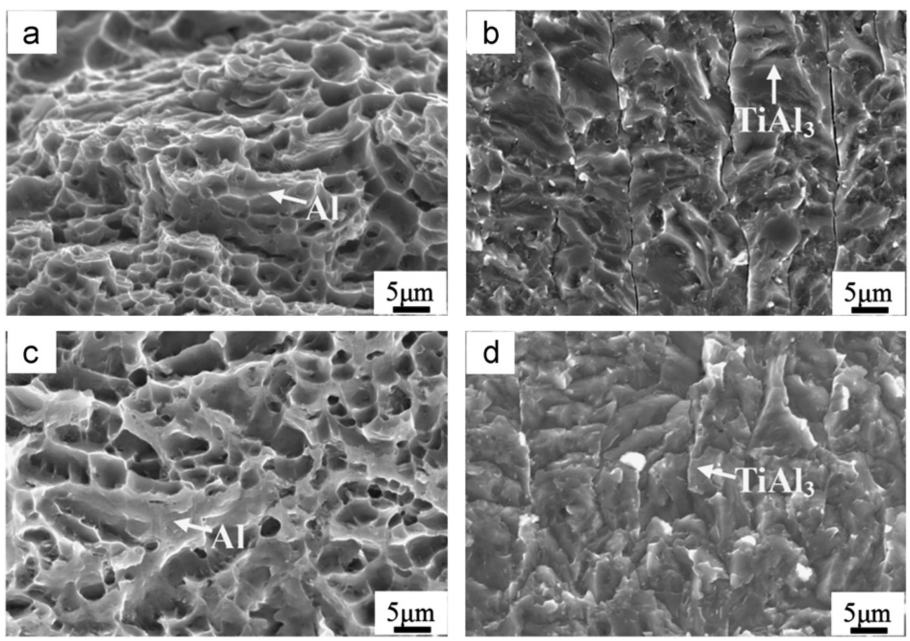

Fig. 14. Fracture surface of different zone in Fig. 13: (a) zone Z1, (b) zone Z2, (c) zone T1 and (d) zone T2.

metal. It should be pointed out, however, that direct butt welding of Ti/Al dissimilar alloys without filler metal still has some limitation, i.e. the process window is comparatively narrow. The laser offset distance toward Al alloy has to be accurately controlled during welding. Provided that the welding parameter is appropriate, the joints can have high mechanical properties.

5. Conclusions

The laser brazing of Ti6Al4V to A6061 plates with 2 mm thickness was conducted by focusing laser beam on aluminum alloy side. The effect of laser offset on the microstructure and mechanical properties of the dissimilar butt joint was investigated. The formation of interfacial IMC layer and its effect on the tensile strength of joint were discussed. The results can be summarized as follows.

(1). Direct welding of Ti6Al4V/A6061 dissimilar alloys with 2 mm thickness by laser beam without filler metal can produce sound brazing joints with good appearance under welding conditions of 4 kW laser power, 4 m/min welding speed, and 0.8–1.0 mm laser offset at aluminum alloy side.

(2). Laser offset has a great influence on the thickness of interfacial IMC layer and the mechanical property of joint. With increasing laser offset, the thickness of interfacial IMC layer decreases, and the tensile strength of joint increases. When the laser offset is 1.0 mm, thickness of interfacial IMC layer is about 0.26 μm, and the average tensile strength of joint is about 64% of the aluminum alloy base metal. The interfacial intermetallic phase is $TiAl_3$.

(3). The joining mechanism of Ti6Al4V/A6061 dissimilar alloys by laser brazing is the formation of intermetallic phase $TiAl_3$ at the interface, which metallurgically connects Ti6Al4V and A6061 plates together.

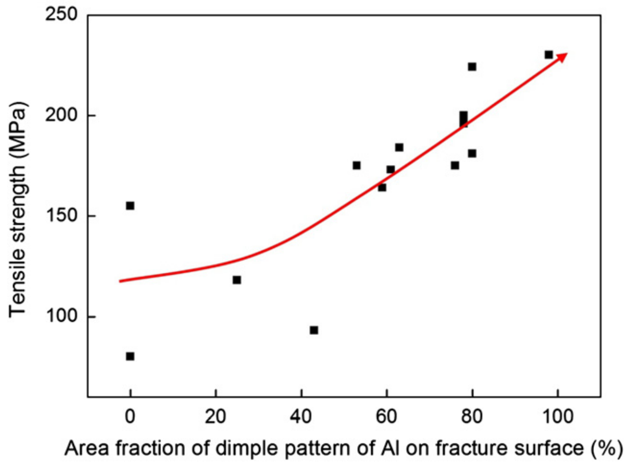

Fig. 15. Relationship between area fraction of dimple pattern of Al on fracture surface and tensile strength of joints.

(4). When the thickness of interfacial IMC layer is decreased by increasing the laser offset, the dissimilar joints tend to fracture in the fusion zone of aluminum alloy, and the tensile strength of joint increases.

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